Baseline Monitoring: Planning, Design, and Prediction for Estuarine Habitat Restoration

W. Gregory Hood *and* ***Steve Hinton***
Skagit System Cooperative

[Editor's note: Figures for Hood and Hinton appear at the end of this paper.]

Abstract
Baseline monitoring is often neglected in habitat restoration. Instead, monitoring usually occurs only after habitat has been restored. Omission of pre-restoration monitoring is a critical error because baseline monitoring facilitates identification of the extent and character of the problem to be solved by habitat restoration, identification of project goals, development of project design, and development of standards for success. Additionally, baseline data provides a standard of comparison for post-project monitoring. In a case study from the Skagit estuary (Washington, USA), we demonstrate how baseline monitoring can be used to determine historic conditions, to plan and design for habitat restoration, and to make predictions about vegetation recolonization and likely fish and wildlife usage of the restoration site. We used GIS analysis of historic aerial photos and found that, over the past 50 years, habitat loss occurred both inside and outside of dikes constructed to convert estuarine marsh to agriculture. We used LIDAR to measure the topography of the lower Skagit Delta, simultaneously sampled vegetation and groundtruthed the LIDAR with 2-cm resolution GPS, and used the GPS data to develop an empirical predictive model of estuarine vegetation distribution based on topography. The vegetation distribution model was linked to the LIDAR model to develop predictions for vegetation colonization after dike removal. Prediction is important because it facilitates planning and management and it also links the restoration and monitoring effort to the scientific method: predictions derived from baseline monitoring are hypotheses that are tested by implementation of the habitat restoration design. Requirements for baseline monitoring of proposed habitat restoration projects need to be incorporated into the bureaucratic structure of institutions that fund or carry out habitat restoration, so that baseline monitoring becomes more common and so that critical information is collected to develop more complete restoration solutions.

Introduction
Institutions and agencies that engage in habitat restoration or provide funds for habitat restoration are increasingly requiring that restoration projects be monitored to ensure that restoration actually occurs, that project goals are met, that adaptive management can be implemented if necessary, and that the science and technology of restoration can be improved. To support large-scale institutional restoration programs and policy, bureaucratic and technical guidance has been developed for monitoring of habitat restoration (Thom and Wellman 1996). This guidance currently emphasizes a triumvirate of implementation, effectiveness, and validation monitoring (U. S. Forest Service 1992, Washington State Joint Natural Resources Cabinet 1999, Oregon Watershed Enhancement Board 2001, Marcot et al. 2002), which are all undertaken after restoration actions have been carried out, i.e., after dikes have been removed or breached, after vegetation has been manipulated, etc. Indeed, this monitoring triumvirate is so well established in the bureaucratic realm that it has been codified in federal law (43 CFR 1610.4-9). However, a fourth category of monitoring, baseline monitoring, is generally omitted from consideration for habitat restoration projects, except in some academic studies (Underwood 1994, Michener 1997). Baseline monitoring is undertaken prior to project implementation, but bureaucratic attention is focused almost exclusively on post-project monitoring.

One exception to this programmatic neglect of baseline monitoring is long-term monitoring of ambient conditions to detect effects of global change or of diffuse anthropogenic impacts on the regional environment (Ward and Jacoby 1992; Puotinen 1994; Kirkman 1996; Wasson et al. 2002). Such ambient monitoring generally concerns itself with diagnosis of poor or declining environmental health over large geographic scales. Baseline monitoring for habitat restoration, in contrast, concerns itself not only with problem diagnosis, but also with change detection from specific and directed actions on a project scale, e.g., restoration of estuarine habitat through dike removal, planting vegetation, controlling exotic species. This paper distinguishes these two very different types of baseline monitoring, and concerns itself with baseline monitoring for habitat restoration, which is far more neglected from a programmatic perspective.

Baseline monitoring for habitat restoration is monitoring or data collection that occurs prior to restoration. It should include historical reconstruction of habitat conditions as well as quantification of current conditions. Omission of baseline monitoring from habitat restoration is problematic because thorough understanding of historic and current site conditions are crucial for successful restoration.

Restoration as a Problem Solving Process

Habitat restoration is a solution to a problem. The problem is low abundance of one or several desirable plant or animal species. The solution is restoration of habitat vital for the species. Common sense problem solving involves answering three simple questions: (1) what is the problem? (2) how do you fix the problem? (3) did the solution actually work? Baseline monitoring plays a vital role in answering all three of these questions. It aids in precisely identifying and quantifying the extent of the problem, i.e., the degree to which habitat has been lost or the type of habitat degradation that has occurred. It informs and supports the appropriate solutions of the problem, suggesting proper goals of the restoration and design details. And finally, it can be used with post-restoration monitoring to evaluate success of the solution, by allowing before/after comparisons (Underwood 1994; Michener 1997). Thus, baseline monitoring is intrinsically necessary for common-sense problem solving, yet surprisingly, it is rarely employed by restoration ecologists or required by managers and funding agencies.

An example from the Skagit River delta (Skagit County, USA) illustrates some of these points (Figure 1). The Washington Department of Fish and Wildlife (WDFW) owns 80-ha of diked land (Wiley Slough, 48º 19′ N, 122º 23′ W) that is drained and planted with corn as part of a wildlife management program targeted towards duck and pheasant hunting (Figure 2). Historical aerial photos from 1956 show that this area was undiked at this time and consisted of tidal marsh and a large network of tidal channels (Figure 3). An aerial photo from 1965 shows dikes in the area, in the same configuration as in 2003. Thus, dikes were constructed in the area between 1956 and 1965. GIS analysis comparing aerial photos from 1956 to 2000 indicates that diking resulted in loss of 6.7 ha of tidal channels landward of the dikes as well as 73.3 ha of marsh habitat. However, an additional and larger amount of tidal channel habitat, 9.6 ha, were lost seaward of the dikes as a result of sediment accumulation (Figure 4, Hood 2003). Elimination of 80 ha of marsh and tidal channel through dike construction reduced the tidal prism for channel reaches downstream from the new dikes, and this loss in tidal flushing caused the downstream tidal channels to re-size through sediment accumulation (Hood 2003). A sediment core from the 1956 location of the downstream portion of Wiley Slough (now silted in) passed through 2 meters of fine silt before encountering coarse sand typical of tidal channel beds in this delta.

Baseline data collection in this case consisted of analysis of historical aerial photos. This analysis identified and quantified the problem, i.e., historical diking caused habitat loss both landward and seaward of the dikes for juvenile chinook salmon (listed as a threatened species under the Endangered Species Act) and other organisms dependent on tidal channels. Such seaward habitat impacts by dikes are frequently overlooked. Baseline data collection helped to identify the spatial extent of the problem, and this could not have occurred without baseline data collection. Baseline monitoring also located and quantified the historical channels precisely, so that restoration goals (e.g., return to historical condition) can be very precisely defined. Quantification of channel habitat loss revealed that the loss amounted to approximately 12% of the existing blind tidal channel habitat in the Skagit delta (in the vicinity of the North and South Fork outlets). Thus, habitat restoration would result in a considerable increase in estuarine habitat for juvenile salmon in this system. This realization has motivated WDFW to decide to restore this site (R. Carman and B. Williams, personal communication). WDFW was additionally motivated to restore the site by the realization that the agency owned the property at the time that it was diked, so WDFW was responsible for the identified habitat impacts. This was a surprise to current WDFW managers who had assumed that the property had been purchased in the 1940s as already diked and drained farmland—an example of lost institutional memory. Thus, baseline monitoring in this case not only identified and quantified a problem, it also identified the responsible party and helped to motivate the solution.

The restoration of the Wiley Slough area has not yet begun. However, project goals that emerge from this baseline data will likely include restoration of the tidal channel drainage network in a configuration and quantity that resembles the historical configuration and quantity. This goal should apply to areas both landward and seaward of the current dikes. Because the smallest channels that could be resolved in the 1956 photos were 1m in width, the abundance and location of smaller channels is unknown, so specification of the project goals will have this resolution limit. Nevertheless, the available resolution of historical channels is relatively fine-scale and certainly a significant improvement over circumstances where restoration proceeded blindly without reference to historical information. The historical photos also provide general information on the type of vegetation present prior to diking: primarily emergent estuarine vegetation with some scrub-shrub and forested vegetation on natural levees adjacent to large channels, such as Wiley Slough and Freshwater Slough (a nearby distributary of the South Fork Skagit River). This inference is consistent with a reconstruction of Skagit delta vegetation communities from historical survey records and maps (Collins and Montgomery 2001). Thus, another project goal should be reestablishment of this general vegetation pattern. The baseline data also provides some guidance for design considerations. Restoration of the 9.6 ha of channel network lost seaward of the dikes requires removing sediments up to 2 m deep in the historical channel. Excavation of such a volume of sediments from the historical channel with heavy machinery would be problematic. Another approach might be to connect Wiley Slough to Freshwater Slough and use river flow from this distributary channel of the South Fork Skagit River to scour out the sediments in lower Wiley Slough. Indeed, maps of the delta from 1874, 1889, and 1897 all show that Wiley Slough was once a branch of Freshwater Slough. While the 1889 map labels the channel "Wiley Slough," the 1897 map calls it " Freshwater Slough (West Branch)." Another design question is whether dikes should be completely removed or merely breached in order to restore the site. The argument for breaching is economic—minimizing cost. The argument for removal is a mixture of pragmatism and ecological benefit. Some dike material will need to be removed to construct new dikes to protect farmland adjacent to the restoration site. Additionally, borrow ditches will need to be filled so that the historical drainage network can be restored without competition from the borrow ditches (Simenstad, personal communication). Complete dike removal is also required to allow sheet flow over the site to restore associated tidal circulation patterns (French and Stoddart 1992) and to allow full exchange of nutrient, detritus, and aquatic organisms across the site. Analysis of the historical and current aerial photos also indicates that dike construction reduced channel sinuosity in nearby Freshwater Slough from 1956 to the present, because the dikes confined floodwaters to Freshwater Slough rather than allowing them to spill out over the marsh in the Wiley Slough area (Hood 2003). Because flood energies were no longer dissipated over the marsh surface after dike construction, the Freshwater Slough channel had to accommodate greater flood flows by widening and straightening. Loss of channel sinuosity has likely resulted in decreased channel habitat diversity in Freshwater Slough, reducing the amount and size of pool habitat and shallow point bar habitat, and thereby affecting large pool-inhabiting fish like sturgeon and small fish, shorebirds, and waterfowl that feed on point bars. Complete removal of the dikes on this restoration site will allow complete tidal and riverine flooding of the site with likely beneficial consequences for channel habitat in lower Freshwater Slough.

The results of baseline monitoring have shown that there have been several significant "off-site" impacts caused by the dikes that enclose the Wiley Slough area. These include loss of channel habitat seaward of the dikes to siltation and loss of channel sinuosity and associated habitat in nearby Freshwater Slough. Thus, post-project monitoring of the effects of dike removal should include not only on-site (landward of the dikes) monitoring, but also "off-site" (seaward of the dikes) monitoring in relevant areas. "Off-site" monitoring locations would include the historical location of lower Wiley Slough and lower Freshwater Slough. Actually, the concept of what is the restoration site is expanded from the area bounded by dikes to the areas that are directly or indirectly influenced by the dikes. Conversely, reference sites for post-project monitoring should be located well away from possible indirect influences of dike removal. In addition to using reference sites as a standard for restoration success during post-project monitoring, the baseline data also provides historical standards against which the success of the restoration can be measured.

Prediction in Habitat Restoration

Prediction is fundamental to the scientific process. Hypothesis testing involves making predictions based on available evidence and theoretical understanding, and testing those predictions against experiments or other observations. Science-based habitat restoration likewise is dependent on making predictions of the outcome of a proposed restoration. Furthermore, the political process involved in habitat restoration also requires predictability for the sake of developing policy and plans regarding habitat management and for the sake of efficiently allocating time, money, and effort to a particular restoration project in confident anticipation of a particular outcome.

Baseline monitoring is essential for making predictions of the outcome of habitat restoration. A common concern for estuarine habitat restoration is what kind of vegetation will colonize a site after dike removal. Baseline data was collected from reference marshes in the South Fork Skagit Delta on vegetation and elevation associations. Survey-grade Global Positioning Surveying (GPS, 2-cm horizontal and vertical resolution) was used to simultaneously collect data on dominant marsh vegetation at each sampling point and the elevation of the point. Nearly 600 data points were collected on random transects in the reference marsh to generate elevation ranges for eleven estuarine plant species (Figure 5). This data was then used in conjunction with remotely sensed elevation data from LIDAR (15 cm vertical resolution; Spencer B. Gross, Inc., Portland, Oregon) to generate a GIS map of predicted vegetation colonization of the restoration site following dike removal (Figure 6). This prediction, generated from baseline data collected prior to project development, was used to convince WDFW habitat managers and duck hunters that habitat restoration on this site will benefit waterfowl in addition to salmon, because the vegetation that will dominate the site consists entirely of waterfowl food plants, i.e., *Carex lyngbyei*, *Eleocharis palustris*, *Scirpus americanus*, and *S. validus* (Burgess 1970, Vermeer & Levings 1977, Butler & Campbell 1987, Gordon et al. 1989, Krapu & Reinecke 1992). In addition to supporting a policy decision to restore the site for the benefit of fish and waterfowl, this prediction generates:

- A restoration goal and a criterion for restoration success—that the site will be colonized predominantly by waterfowl food plants
- An agenda item and standard for post-project monitoring.

Project Benefits of Baseline Monitoring

In addition to answering the three fundamental questions of common sense problem solving and generating predictions, as previously described, baseline monitoring has several other benefits for habitat restoration. A decision to employ baseline monitoring for a potential restoration project encourages an early commitment to project monitoring. It requires early development of a monitoring plan for baseline and post-project monitoring and it encourages coordination and integration of both the baseline and post-project phases of monitoring. When baseline and post-project monitoring are anticipated prior to initiation of the restoration project, a clear focus on before/after comparisons and on hypothesis testing naturally results. This early commitment to monitoring and early integration of the design of baseline and post-project monitoring should point out that restoration monitoring is a holistic process that begins prior to any physical restoration of a site and continues after physical restoration is complete. Baseline and post-project monitoring are not really two distinct types of monitoring, they are part of one whole monitoring or problem-solving process.

The fact that baseline and post-project monitoring are required to answer the three fundamental questions of problem-solving ([1] what is the problem? [2] how do you fix the problem? [3] did the solution actually work?), shows that monitoring is not a luxury in habitat restoration. It is absolutely necessary. Likewise monitoring should not be treated as an afterthought to restoration, as is often the case. It is part of project (problem and solution) identification and design development, so an early commitment to baseline and post-project monitoring is essential.

The Bureaucracy of Baseline Monitoring

Agencies that fund or carry out habitat restoration, generally focus only on post-project monitoring, compartmentalized into three categories: implementation, effectiveness, and validation monitoring (U. S. Forest Service 1992; Washington State Joint Natural Resources Cabinet 1999; Oregon Watershed Enhancement Board 2001; Marcot et al. 2002;, 43 CFR 1610.4-9). This bureaucratic monitoring paradigm dominates habitat restoration funded by state and federal agencies. Because baseline monitoring is missing from this paradigm, there is little or no institutional support or funding for baseline monitoring, or even awareness of the value of baseline monitoring. Consequently, baseline monitoring is the exception rather than the rule in habitat restoration. This deficiency could be programmatically addressed. Many bureaucratic programs that fund restoration require feasibility studies or design studies prior to funding a restoration project. Baseline monitoring should be a required element in these studies, and the studies should show how post-construction monitoring will complement the baseline monitoring. Funding for implementation or construction of restoration projects should be contingent on collection and analysis of baseline data, and a demonstration of how baseline data has contributed to development of project goals, restoration design, and post-project monitoring design. A requirement for baseline monitoring in habitat restoration projects it crucial to ensure that restoration projects are adequately identified, defined, solved, and monitored after completion. Incomplete identification and characterization of a problem leads to an incomplete, or a failed, solution of the problem.

Consider the Wiley Slough example. Without baseline data collection on the site history, proposed restoration of the area would have very likely have focused only on areas landward of the dikes. Historical habitat impacts seaward of the dikes would have been completely overlooked. The importance of removing dikes entirely to restore natural hydrologic processes affecting habitat diversity in Freshwater Slough would also likely have been missed. Baseline monitoring helped to define the true extent of habitat impacts resulting from dike construction in the Wiley Slough area, and this was necessary to develop a complete solution to the problem of lost estuarine habitat at this site.

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Maps

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Personal Communications

Randy Carman, Washington Department of Fish and Wildlife, Olympia, Washington.

Charles Simenstad, School of Aquatic Science and Fisheries, University of Washington, Seattle, Washington.

Brian Williams, Washington Department of Fish and Wildlife, LaConner, Washington.

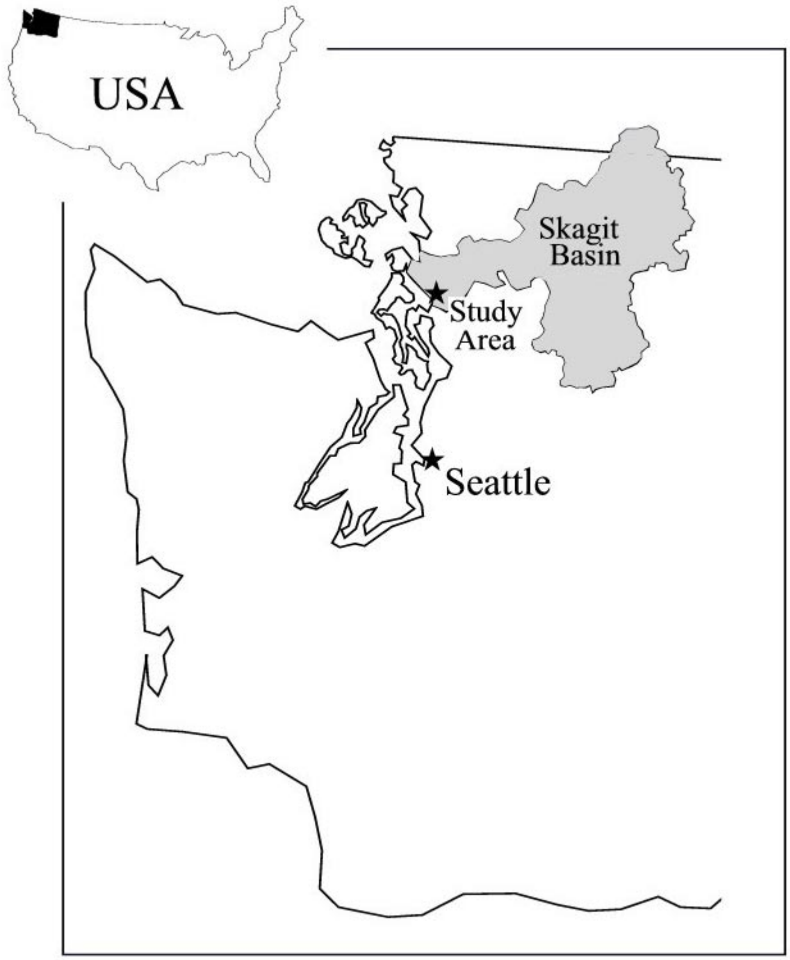

Figure 1. Vicinity figure, showing the general location of the Wiley Slough restoration project.

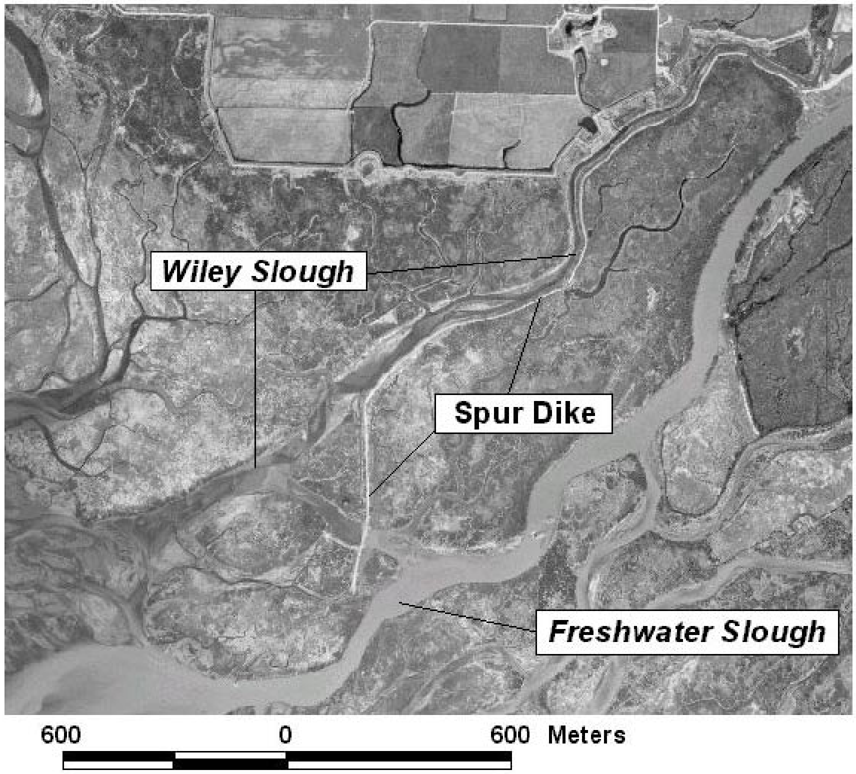

Figure 2. 1956 aerial photo of the Wiley Slough area. A spur dike, not enclosing any area, was present at this time and was the first stage of dike construction on this site. Freshwater Slough is the major distributary of the South Fork Skagit River. Scale is 1:15,000.

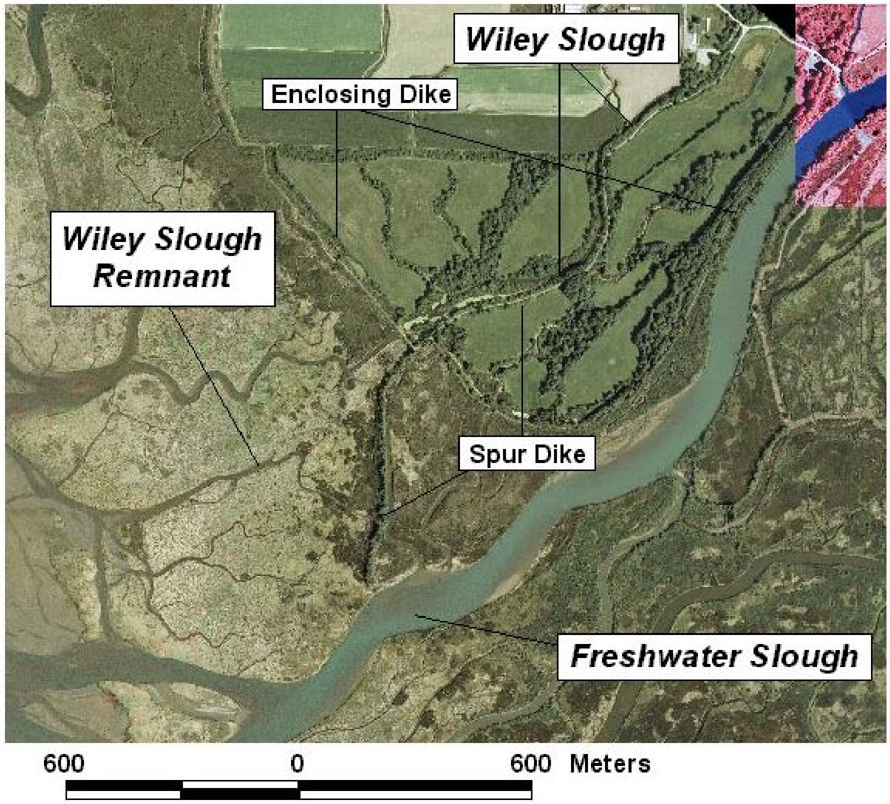

Figure 3. 2000 aerial orthophotos of the Wiley Slough area. Photo coverage consists of a mix of true color and infrared photos. Scale is 1:15,000.

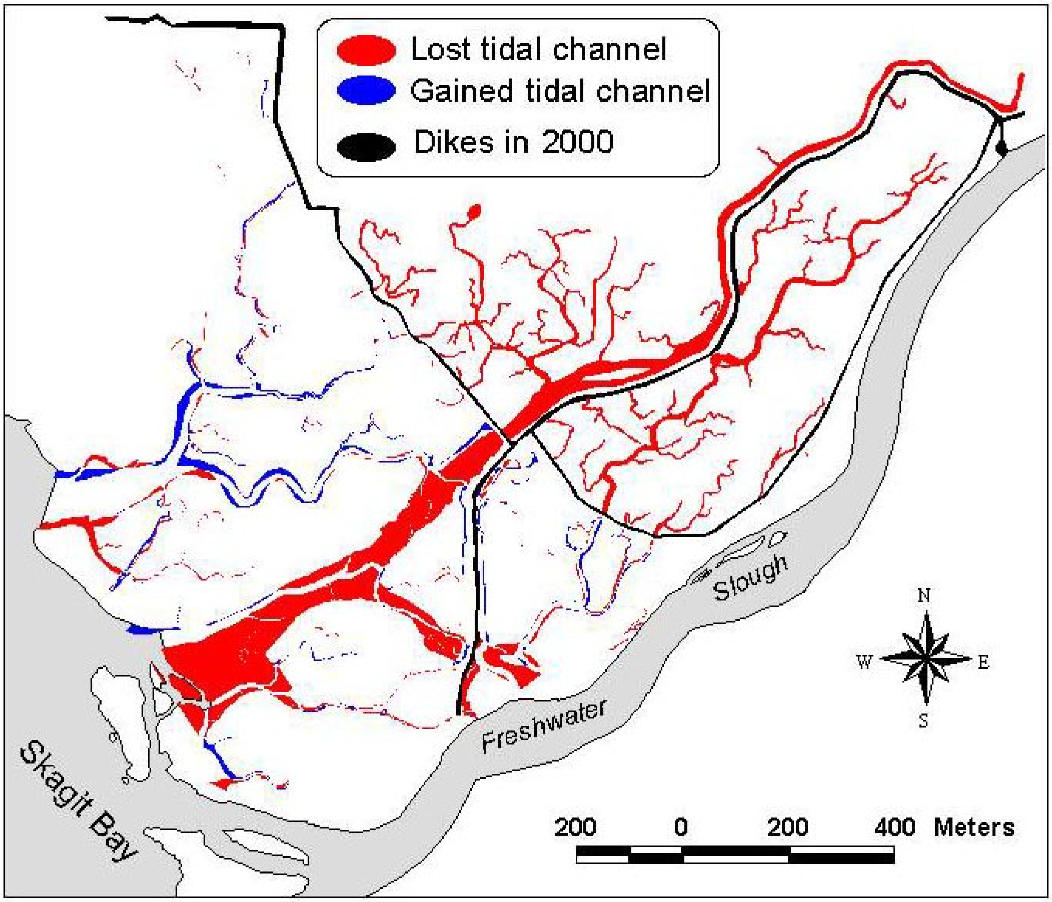

Figure 4. Tidal channel habitat lost from 1956 to 2000 in the Wiley Slough area. Habitat area lost outside of the dikes resulted from channel sedimentation, which was caused by loss of flushing tidal volumes eliminated by upstream dike construction.

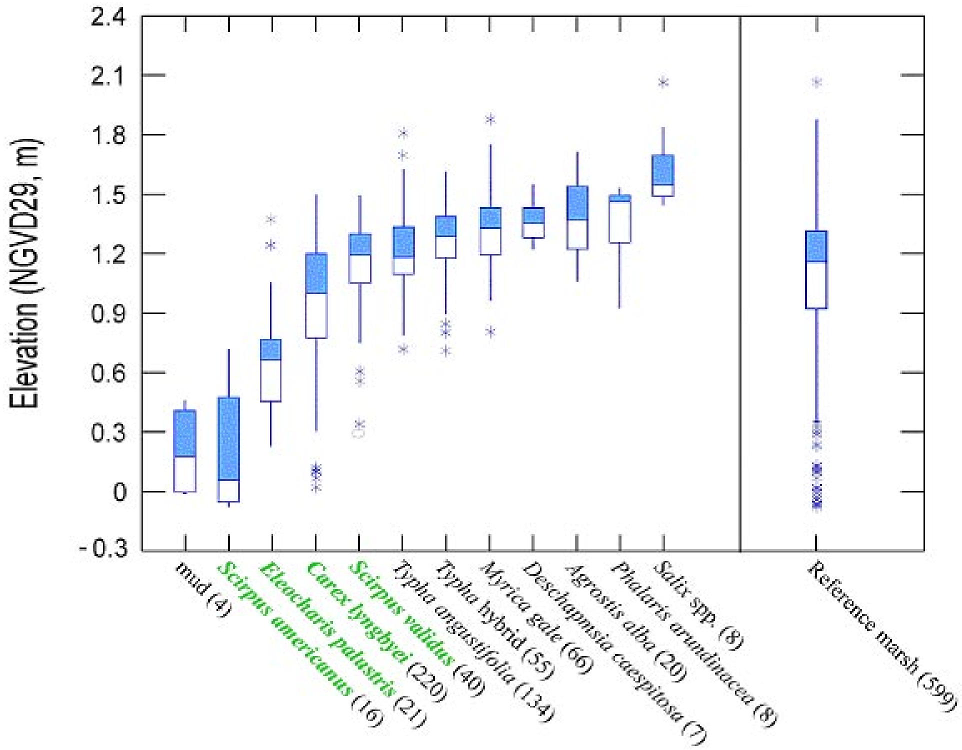

Figure 5. Box and whiskers plot of elevation ranges of plant species growing in natural reference marshes in the Skagit tidal marshes. Species in green are documented waterfowl foods. Numbers in parentheses are numbers of data points for each species and site.

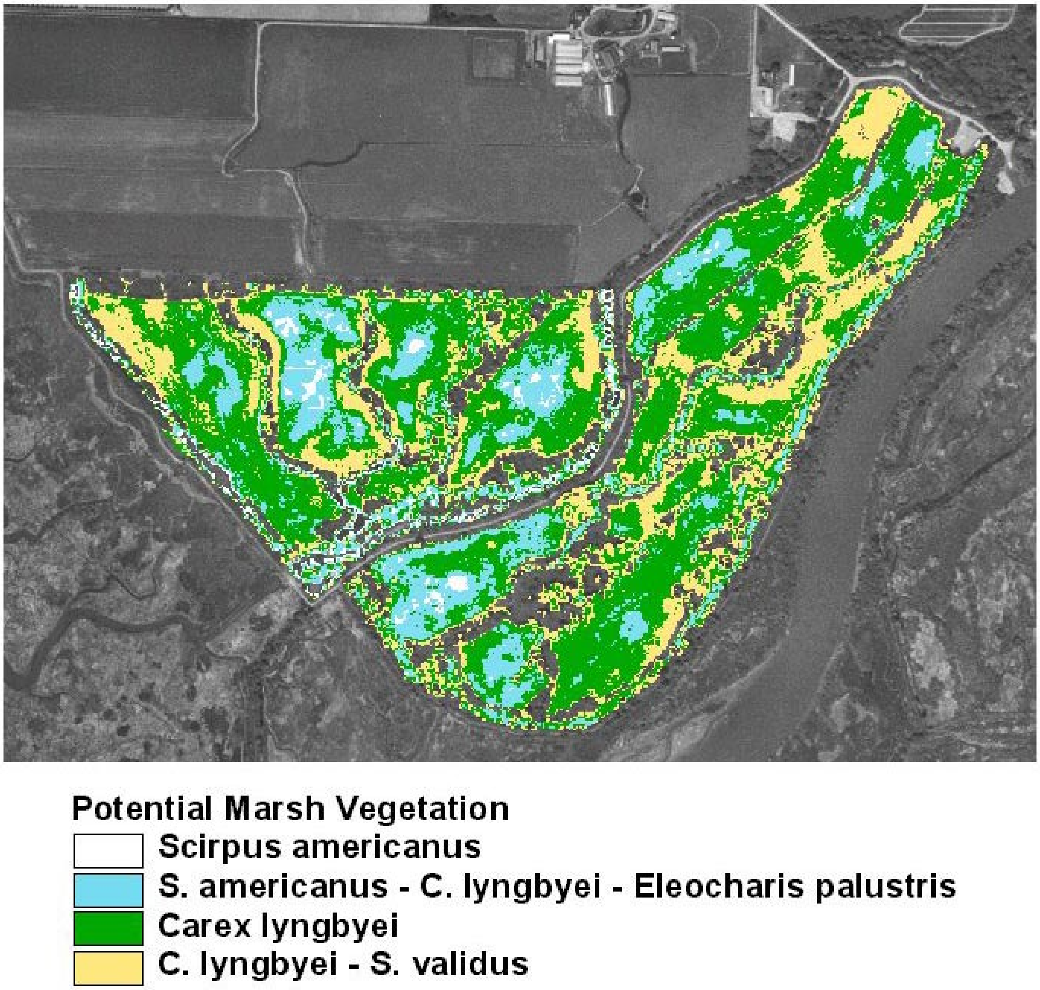

Figure 6. Predicted distribution of dominant emergent estuarine plant species after dikes are removed from the Wiley Slough area. Predictions are based on the vegetation-elevation data depicted in Figure 5. Salinity is not an important predictive factor in this instance because close proximity to the Freshwater Slough, the dominant distributary channel of the South Fork Skagit River, causes soil pore-water to generally be fresh in this area. All predicted species are documented waterfowl foods.